

# Assessment of the Vulnerability of the Southwestern Coast of Benin to the Risk of Coastal Erosion and Flooding

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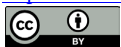
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## Abstract

The coastal zone of Benin is inherited from the last marine oscillations of the Quaternary. A rich and very fragile environment, it presented until the 1960s, a shoreline in dynamic equilibrium over the entire 125 km of coastal line. Since the 1960s, with the construction of important development infrastructures (ports, dams, groins), the Beninese coast is now subject to risks of coastal erosion and seasonal flooding due to the overflow of lagoon water bodies. The present study, based on socio-economic surveys in the communes of Ouidah, Comè and Grand Popo, exposes the extent of coastal risks and socio-economic and environmental damage in the southwestern coastal zone of Benin. The results show that in terms of land, 2.9 ha and 5.7 ha of land have been permanently lost to coastal erosion in the communes of Ouidah and Grand Popo respectively. Similarly, 212 ha of crops of all types were affected by the flooding, including 35 ha destroyed, *i.e.* 6.67 ha, 11.3 ha in Comè, 4.67 ha Ouidah and 14 ha Grand Popo. Also, 6435 buildings were affected, and 4235 huts were damaged. In addition, working tools, food stocks and other items are counted among the losses recorded by coastal hazards with their corollaries of diseases. The cost of losses and damages in the 08 districts amount to 418,000,000f cfa of which 266,000,000f cfa of damage and 152,000,000f cfa of loss.

## Keywords

Beninese Coast, Coastal Erosion, Floods, Socio-Economic Surveys, Impacts of Coastal Risks

## 1. Introduction

Floods are one of the most important extreme weather events in West Africa. They are becoming increasingly recurrent and aggravating and are seen as potential consequences of climate change in the region [1]. The manifestations of floods are observed at the scale of transboundary river basins as well as inland river basins of the countries. In 2007 and 2009 more than 800,000 people were affected in West Africa, but 2010 represents the year with the highest number of affected people and fatalities [2]. About 1.9 million people were affected in 2010. These floods are mostly reported in the Ouémé, Niger and Mono basins. Coastal erosion in Benin is mainly of natural origin. However, economic activities and the installation of certain infrastructures contribute to its amplification. Flooding and coastal erosion are the natural disasters that Beninese coastal communities are regularly confronted with. In recent decades, coastal risk phenomena seem to occur at a faster pace and are potentially more dangerous and devastating. The aggravation of the consequences of coastal hazards is due to two major factors: climate change and urban expansion as a result of population growth and rural exodus. Current knowledge on the effects of natural disasters shows that the areas impacted are diverse and the projections of future impacts are very alarming in the agriculture, livestock, fisheries, education, water and sanitation and health sectors. Faced with this trend, which could slow down and then reverse the progress made from generation to generation, it is imperative for developing countries such as Benin to become more aware of the consequences of coastal hazards that weaken the living conditions of the population. The present study based on socio-economic surveys in 08 districts and 16 villages from 03 municipalities of the south-western coast of Benin, namely Ouidah, Comè and Grand Popo, aims to evaluate the impact of coastal risks and highlight the induced damage caused to surrounding structures and living communities.

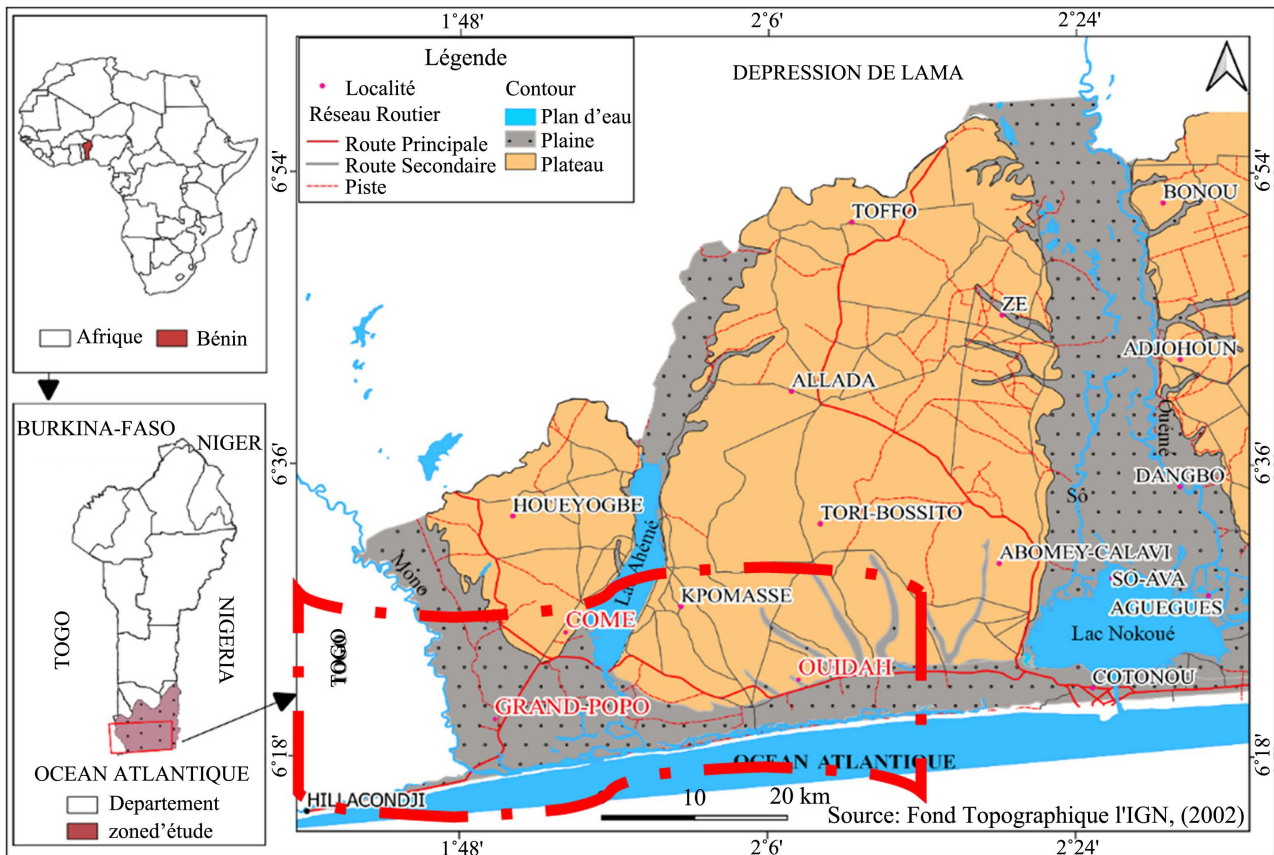
## 2. Presentation of the Study Area and Distribution of Coastal Risks by Municipality

### 2.1. Study Area

The study area located in the coastal zone of Benin covers three (03) municipalities Comè, Ouidah and Gand Popo (**Figure 1**). These 3 municipalities are most vulnerable to risks of flooding and coastal erosion which dangerously affect the population.

### 2.2. Climatic Factors

The climate of the study area is sub-equatorial and bimodal with four seasons well marked by: 1) a large rainy season from mid-March to mid-July; 2) a small rainy season from mid-September to mid-November; 3) a large dry season from mid-November to mid-March; and 4) a small dry season from mid-July to mid-September. The amount of water collected during the year according to ASECNA



**Figure 1.** Geomorphological map of the study area in the coastal zone of Benin.

(2018) varies between 950 and 1300 mm with a much higher importance in the East.

The average temperature varies very little (about 27°C in Cotonou and Ouidah). It remains high in the dry season (28.33°C on average) and drops in the rainy season (27.46°C). Maximum temperatures are generally recorded during the months of February to April, which correspond to the peak of the dry season, with sunny days (31°C - 33°C) followed by cool nights (23°C - 24°C). The lowest temperatures are observed between July and August (25°C).

The predominant winds along the Cotonou coastline are those from the SW (64%) with a high frequency during the months of February, March, April, June and October, with average monthly speeds of 4.4 m/s (ASECNA, 2012). Those from the WSW (16.07%), which are more frequent during the months of July, August and September, have average monthly speeds that oscillate around 6 m/s (ASECNA, 2012). SSW winds (14.40%) are very infrequent in recent decades; their monthly mean speeds decrease from 5 m/s in January to 3.6 m/s in March, November, and December (ASECNA, 2012).

### 2.3. Geology and Geomorphology

The study area belongs to the coastal plain of Benin, a low-lying and humid area, serving as a transition between the sea and the continental domain represented

by the bar land plateaus. This plain is made up of a series of coastal strips forming, between the edge of the plateaus and the shoreline, three generations (the inner strip of “yellow sand”, the middle strip of “gray to white sand” and the outer strip of brown sand) interspersed with marshy depressions. The altitudes of these cords are of the order of 5 to 8 m for the yellow sands, 2 to 3 m for the grey sands and those of the brown sands do not exceed 5 m above sea level.

Benin’s beaches are made up of medium sands with midpoints between 1.5 and 2.5, except for the eastern ends of the mouths and the backwater trapping areas where the sediments are coarser and finer respectively. Mineralogical analysis shows that these sands are 90% quartz and contain a suite of heavy minerals, rich in brittle minerals such as garnet and amphiboles [3]. Furthermore, [4] studying the granulometry of the sediments of the submarine beach in front of the Bouche du Roi showed that for the depths of –11 m, the median diameters of the sands are, with rare exceptions, between 0.01 and 0.03 mm at the western end of the mouth, while to the east, it is the values lower than 0.06 mm that become exceptions.

#### 2.4. Hydrological Factors

The study area belongs to the western fluvio-lagoon complex fed by the Mono and Couffo rivers, which includes: Lake Ahémé, the Aho channel and the coastal lagoon, all associated with a very dense network of anastomosing tidal channels often bordered by mangroves.

- The Mono, which rises in the heights of Bafilo-Tchamba in Togo, is 527 km long and drains, with its tributaries the Anie, the Ogou and the Sazué, a basin of 21,500 km<sup>2</sup> in Togo and Benin. The hydrology of the river used to be characterized by a single flood in September with flows that could reach 680 to 700 m<sup>3</sup>/s [5] [6] [7] and by a very pronounced low-water period from December to April, with a very low or even zero flow, but this was disrupted following the commissioning of the Nangbeto dam, which, while modifying this regime, now makes the flow permanent in all seasons.
- The Couffo River is 190 km long with an altitude of 240 m and drains a catchment area of 3000 km<sup>2</sup>. It originates in Togo in the Djami Mountains, near the village of Tchetti (Benin) and feeds the Ahémé Lake in the North. The Couffo has two flood periods per year, in June-July for the first and in September-October for the second, with flows of around 16 m<sup>3</sup>/year [8] [9].
- Lake Ahémé is 24 km long with a width varying between 2 and 5.5 km. Its surface area at low water is 78 km<sup>2</sup> and 100 km<sup>2</sup> at high water [10]. The depths are less than 1.5 m in the south of the lake and vary between 1.5 and 2.5 m in the center and north of the lake. However, at the entrance to the Couffo River, which is its main tributary, the depths are relatively great: 3 to 4.5 m [11].
- The coastal lagoon is 60 km long (from Togbin to Agbanakin) with a surface area of about 12 km<sup>2</sup>, and consists of a narrow channel up to 500 m wide that runs parallel to the coast from Agbanakin in the west (Grand Popo), to Tog-

bin in the east (Abomey-Calavi). The coastal lagoon and Lake Ahémé are linked by a channel called the “Aho channel” which is 10 km long.

All these water bodies form a lagoon system supplied not only with fresh water and sediments by the Mono and Couffo rivers, but are also in intercommunication with the sea through a complex mouth called “Bouche du Roi”.

The oceanic water mass located in the study area is characterized by swell and tide, which are the two major oceanic forcings that control the dynamics of the area on the one hand, and influence its hydrological system on the other. According to the works of [8] [12] [13], the tide is of the semi-diurnal type with extreme tidal ranges of +1.95 m and -0.20 m and an average amplitude generally around one meter (microtidal type). The direction and regime of the swells are linked to storms in the South Atlantic, particularly those generated by the Saint Helena High, and secondarily to local winds. They show two swell seasons: one, with low swell heights (0.4 to 0.5 m on average) from October/November to May and the other, during which heights reach and exceed 2 m during the boreal summer from June to September. With a period between 10 s and 15 s and an average frequency of 11 - 12 s, the swells have constant directions and show a predominance of S to SSW directions for the first swells and SSW to SW for the second. The obliquity of the swell at break-up in relation to the shore varies between 4° and 9°, with an average around 6° - 7°. It causes a coastal drift current directed from West to East and whose speed measured at Cotonou is about 0.3 to 1 m/s. This current is responsible for the transit of 1.2 to 1.5 million/m<sup>3</sup> of sand from Lome (west) to Cotonou (east) along the coast of the Gulf of Guinea each year [12] [14] [15] [16] [17]. The salinity of the marine waters varies from 34 to 36 g/L, the surface temperature varies from 27°C to 30°C in the warm season, and from 22°C to 26°C in the cold season.

## 2.5. Socio-Economic Aspect

The economy of the coast, like the national economy, is characterized by a predominantly primary sector (more than a third of domestic wealth). Agriculture is the main activity, with 80% of the population living in rural areas and working mainly on food crops. To this activity must be added livestock breeding, fishing, processing and handicrafts, natural resources, trade, industry, tourism and hotels, etc. The existence of lowlands, flood plains favorable to agriculture, pastures, farmers' and stockbreeders' organizations and supervision and financing structures, is the basis for a diversity of speculations. These include food crops (maize, sorghum, cassava, rice, cowpeas, sweet potatoes), market garden crops (onions, tomatoes, carrots, peppers, leafy vegetables, okra, peppers, tomatoes) and cash crops (pineapples, peanuts, oil palms, cashew trees, etc.). The products from these productions are primarily intended for self-consumption, but also for the marketing of the surplus, apart from cotton, which is exclusively commercial [18].

Livestock breeding in the coastal areas is practiced as a secondary activity. It is a small-scale livestock operation, essentially involving cattle, goats, sheep, pigs,

aulacodes, poultry and rabbits. The poultry and the aulacode are becoming more and more important, given the organization and the size of the herd. The breeding system, which at the beginning is essentially of hut, is becoming more and more modernized.

Fishing is relatively well developed thanks to the many lakes and rivers and mobilizes many people, both nationals and foreigners (mainly from Ghana and Togo). It is practiced in several forms: continental fishing developed in rivers and fish ponds using nets and acadjas, artisanal maritime fishing which is practiced using motorized boats or not with nets along the coast (fishing with beach seines, fishing with rotating seines, fishing for anchovies, fishing with gillnets, fishing with hooks and fishing for sharks...) and industrial maritime fishing which is done using boats (in Cotonou). Fishing products include fish (tilapia, catfish, etc.), shrimp, crayfish, skate, mollusks, sardinella, bars and crabs. Traditional salt farming is the main activity of women in the coastal region after trade. It mobilizes about 2000 to 5000 people and serves as a source of income for several rural households in the area. This seasonal activity, which consists of exploiting and manufacturing salt from salt marshes, is well developed in the communes of Ouidah (Djègbadji and Avlékété), which occupy first place with (66.49%), Grand Popo (Avlo) (27.38%) [19].

In terms of tourism, the coastal area of Benin offers enormous possibilities. The beauty of its lagoon landscape and its beaches has given it numerous tourist potentialities of historical, cultural and eco-tourist types. Here are the main circuits and sites: the lakeside villages of Ganvié and Sô-Tchanhoué in the commune of Sô-Ava which attract thousands of tourists every year; the picturesque sites along the banks of Lake Ahémé from Possotomé to Bopa (Agonsa) and that of the Couffo River. The picturesque beaches (Hillacondji-Avlo (Grand-Popo), Djondji-Bah (Ouidah), Bah-Togbin (Abomey-Calavi), Togbin-Fidjrossè-Toklégbé (Cotonou) and Ekpè-Kraké (Sèmè). The "Slave Route": the final part of the route taken by the slaves in Ouidah. This route measures about 3 km and is marked by places of memory, monuments, and by statutes. The Fishing Road: Located along the coast, the fishing road extends over 30 km between Fidjrossè (Cotonou) and the Door of No Return at Djègbadji beach (Ouidah). It is characterized by the beauty of the lagoon landscape, the mangroves, the islands of Djondji and Djègbadji, the beaches with coconut trees, the maritime facade and the purity of nature with several sacred sites: the Temple of the Python (Ouidah), the sacred forests of Savi, Kpassè, Avlékété and that of Houakpè Daho (Ouidah), the sacred place "Mitogbodji" (Comè). In addition to these tourist attractions, many hotels, bars, restaurants and maquis line the coastline and have a satisfactory level of equipment and hotel infrastructure compared to other cities in the country.

### **3. Assessment Methodology**

#### **3.1. Impact of Coastal Hazards**

The methods used for the assessment of coastal hazards take into account the

nature of these hazards (coastal erosion or flooding) and the periodicity of occurrence during the year.

### 3.1.1. Manifestation and Periodicity of Coastal Risks

In general, the study area covers 3 communes (Ouidah, Comé, and Grand Popo) and 8 districts (Ouidah VI, Djègbadji, Avlékété, Comè, Agatogbo, Grand Popo, Avloh, Agoué,) where the populations periodically suffer the harmful effects of flooding or coastal erosion. The occurrence of the manifestation of these coastal risks is presented in the figure below (Figure 2).

### 3.1.2. The Different Levels of Socio-Economic Surveys

For the assessment of the impacts of coastal hazards a participatory approach based on a mixed research method was applied. This involved first of all exchanges with stakeholders (structures and organizations), then quantitative surveys and qualitative interviews (focus groups and interview guides). The different phases of this evaluation are data collection through surveys, validation and data cleaning.

- The survey is based on a sample of 246 households made up of women and men aged 18 and over. The sample was selected to be representative of the population by residence, age and gender based on the respective proportions of the INSTAD specifications. It should be noted that the respondents were exposed to coastal risks and were available and motivated to receive the interviewers with a clear interest in flooding and coastal erosion. The table below (Table 1) presents the number of respondents by gender and district. The size of the households surveyed ranged from 5 to 9 people, with a greater number of men than women, in the 35 to 49 age group and in the 50 to 64 age group. The level of education of the people surveyed is very diversified with a good number of people with very little education (18% to 45%) followed by a large number of people with only elementary school education (10% to 40%). The activities carried out by the respondents are dominated by agriculture, livestock and fishing, followed by trade.

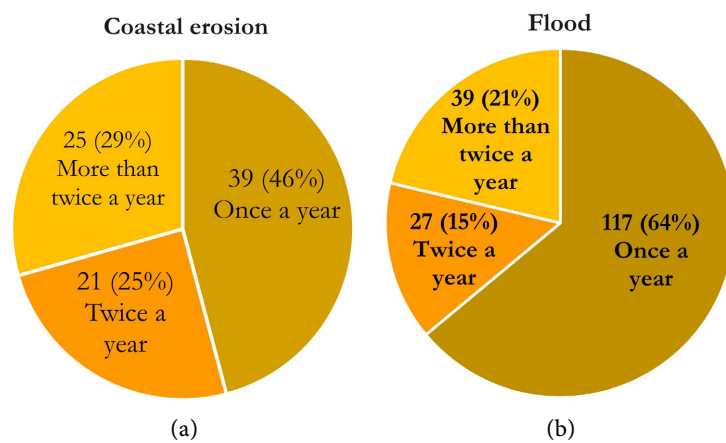


Figure 2. Occurrence of coastal hazards in the year. Source. Survey results, 2022.

**Table 1.** Profiles of respondents by commune, by age/sex and by level of education.

<b>Municipality</b>	<b>Ouidah</b>		<b>Comé</b>		<b>Grand-Popo</b>	
Natural disasters	Flooding	Coastal erosion	Flooding	Coastal erosion	Flooding	Coastal erosion
<b>Age</b>						
18 - 34	19%	0%	0%		26%	23%
35 - 49	33%	50%	25%		39%	43%
50 - 64	29%	50%	35%		21%	23%
65+	19%	0%	40%		14%	10%
<b>Gender</b>						
Male	71%	50%	75%		64%	71%
Female	29%	50%	25%		36%	29%
<b>Level of education</b>						
None	38%	25%	45%		25%	18%
Primary not completed	33%	38%	20%		40%	36%
Completed primary school	10%	0%	10%		8%	10%
Secondary 1st cycle	14%	25%	25%		17%	23%
Secondary 2nd cycle	5%	13%	0%		7%	9%
Higher education 1st cycle	0%	0%	0%		1%	3%
Higher education 2nd cycle	0%	0%	0%		1%	0%
<b>Household size</b>						
1 to 4 persons	43%	13%	21%		28%	22%
5 to 9 persons	52%	88%	68%		59%	64%
10 persons and more	5%	0%	11%		13%	14%
Observation	21	8	19	0	141	77

Source: Survey results, 2022.

The analysis of the collected data is done by taking into account the indicators identified during the surveys using the STATA software. The main measure of impact is the proportion of damage caused to people, their socio-economic activities and their human environment. The objective is to highlight the importance of the impacts of coastal hazards on land and socio-economic activities.

## 4. Results and Discussion

### 4.1. Extent of Coastal Hazards in the Study Area

The magnitude of coastal hazards varies from one municipality to another and by hazard.

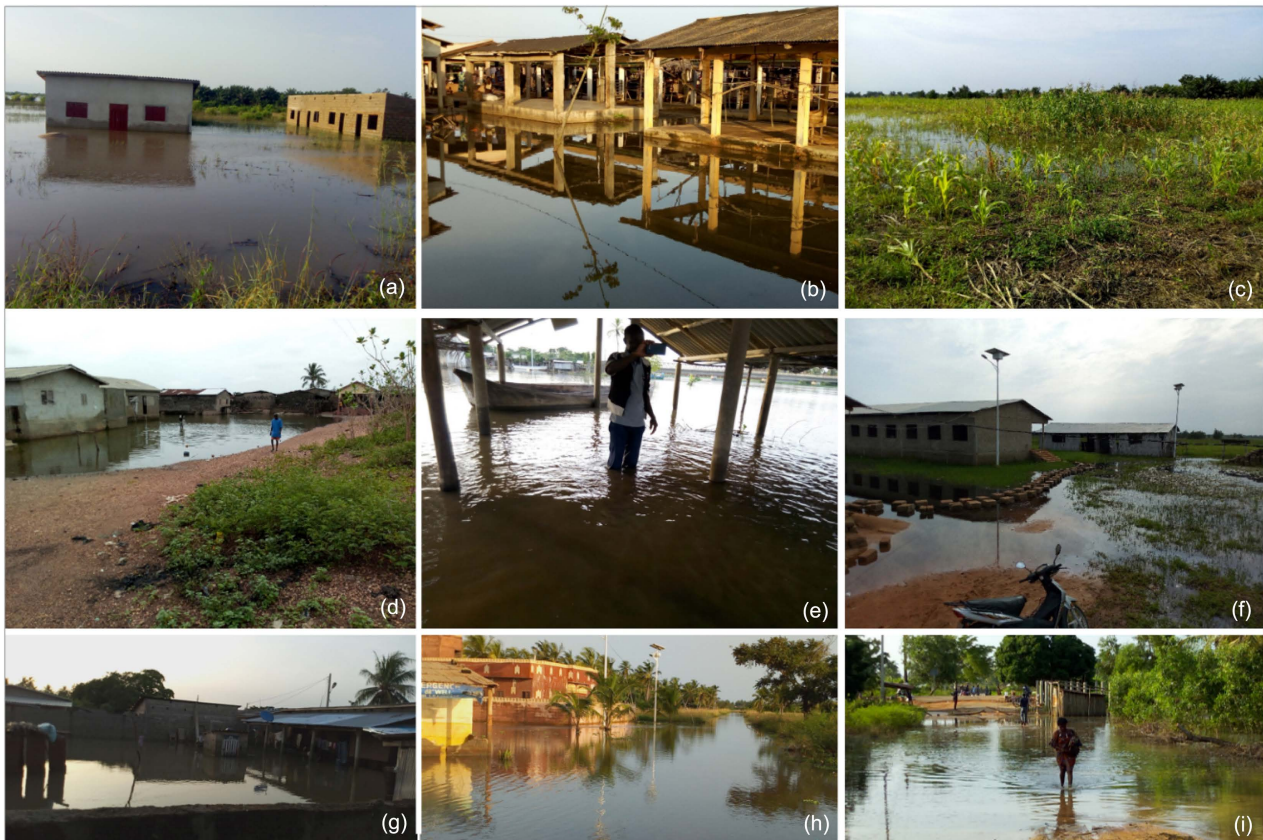


### Occurrence of Coastal Hazards

The two coastal hazards occur with varying magnitudes from one municipality to another. **Figure 3** shows the extent and distribution of these two coastal hazards in the different districts of the study area.

Examination of this figure shows that the commune of Grand Popo is the most vulnerable to the two coastal hazards considered (**Photographic Plate 1**). Indeed, with respect to flooding, the district of Avloh, which straddles the coastal lagoon and the sea, is the most affected. All the villages surveyed (Avloh Village, Hockoué, Gnibohoué, Gnihoué, Sodomè and Gninhouitimè) suffer enormously from the effects of flooding almost every year. Similarly, the districts of Grand Popo Centre, Agatogbo (Comè), Djègbadji and Avlékété (Ouidah) also experience the harmful effects of flooding, but to a lesser degree.

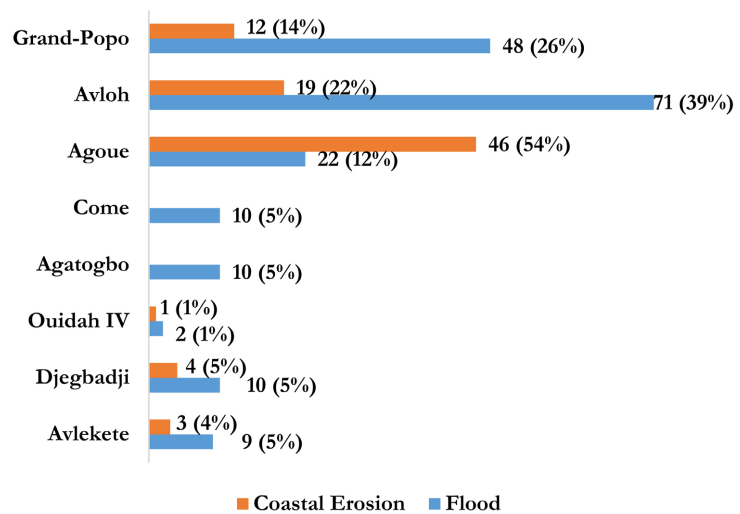
For coastal erosion, the district of Agoué (Grand Popo) is greatly affected with many houses and infrastructures already swallowed up by the sea (**Photographic Plate 1**) and others on the verge of disappearing if nothing is done. It should also be noted that several waves of storms that occurred in November 2021 threatening the populations of Hillacondji forced the prefectural authority to proceed with the eviction of over 200 households (**Photographic Plate 2**).



**Photographic Plate 1.** Southwestern coast of Benin: Views of the damage caused by the October 2019 flood (a) Submerged house in Kétchahoué (b) Market in Onkihoué (c) Flooded corn fields in Gativé (d) Palaver hut in the Onkihoué market (e) Flooded concession in Onkihoué (f) Flooded track connecting Onkihoué and Avloh (g) Flooded track connecting Hèvè and Avloh: Grand Popo, (h) flooded neighborhood in Guézin (Comè) (i) CEG Dohi flooded (Comè).



**Photographic Plate 2.** Littoral sud-ouest du Bénin: Views of damage caused by coastal erosion in the commune of Grand Popo 2021-2022. (a) Buildings of the Christian celestial church completely in ruins (Ayiguinnou) (b) Destroyed houses in Hilacondji (c) Completely destroyed rest area in the filaos district of Agoué (d) Completely eroded shoreline in Agoué (e) Houses damaged by coastal erosion in Kindjèhoué beach).



**Figure 3.** Statistics on the distribution of coastal risks by municipality. Source: Survey results, 2022.

## 4.2. Financial Harm from Impacts.

### 4.2.1. Impact on the Environment, Health and Expenses of Affected Populations

The effects of flooding and coastal erosion on the environment and land are

enormous in terms of the losses and damage recorded. Coastal erosion nowadays is advancing exponentially and causing the accelerated disappearance of ecosystems and habitats such as coastal reefs and mangroves, forcing the local populations to abandon their homes. In total, the 06 districts (of the communes of Grand Popo and Ouidah) have lost approximately 8.6 hectares of land due to coastal erosion. As for the flooding, it affected 212 hectares of fields. A total of 6437 buildings were affected, 4235 huts were damaged, 09 latrines and wells were affected, 02 health centers, 03 schools were partially or totally destroyed in the last 5 years. The total cost of damage and losses is estimated at 253,049,000 CFA francs, with 231,026,000 CFA francs of damage and 22,023,000 CFA francs of losses in all the districts surveyed. According to the survey data (Figure 4(c)), 45% of households do not always have latrines and relieve themselves in the open air.

Fecal matter combined with decomposing waste pollutes the water and leads to foot infections and waterborne diseases when polluted well water is consumed. Among these diseases, the most recurrent are: malaria (29%) which affects more children, diarrheal diseases (13%), cholera (7%) and many others (Figure 4(a) and Figure 4(b)). In addition, during periods of high water, the risk of drowning of learners is quite high, as is the interruption of classes and the

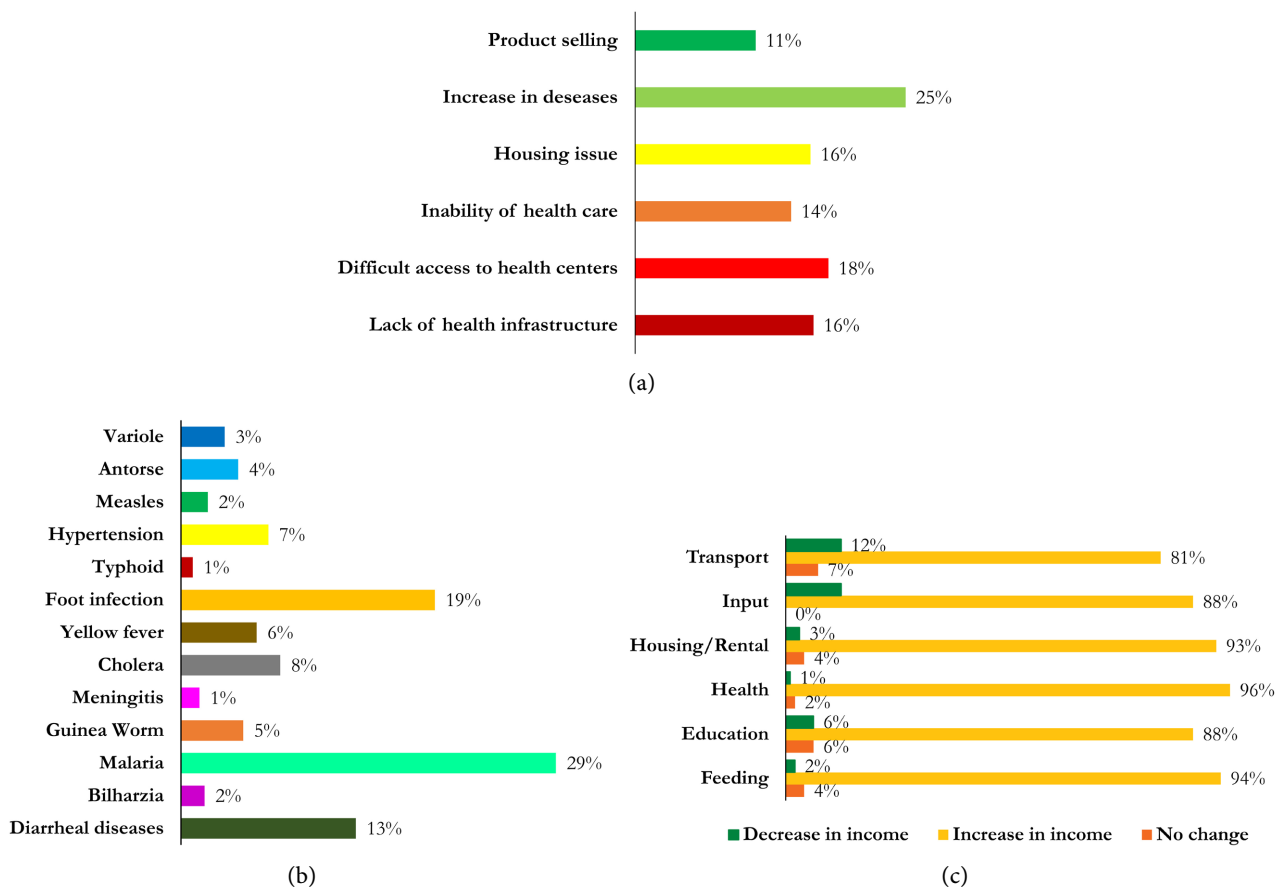


Figure 4. Coastal hazards and human health: (a) Increased disease and (b) Recurrent disease, (c) Impacts on household expenditures. Source: Survey results, 2022.

closure of schools in riverside localities. All these effects make the community's access to basic services such as health, drinking water supply and transportation vulnerable. Furthermore, observation of **Figure 4(c)** shows that coastal hazards have a considerable impact on various common household expenditures for treatment of flood-related diseases, food, and housing. For example, the surveys show that: 96% of households report an increase in expenditures for medical care, 94% for food, 93% for housing or rent, 88% for education, 81% for agricultural inputs (See **Figure 4(c)**).

#### **4.2.2. Impact on Socio-Economic Activities, Food Security and Income of the Populations Surveyed**

Although the water has receded in some areas, it is clear that the local populations affected are still highly vulnerable: their homes have been destroyed, they have lost a large part of their harvest and their stock of food and seeds, and their economic activity has been temporarily interrupted. Apart from the heavily affected agricultural sector, the others are not spared. The damage due to coastal erosion and flooding listed mainly concerns plantations and crops, fish ponds, the number of damaged huts, sanitation infrastructure (wells, latrines...), buildings (school and health center). The losses, on the other hand, concern the monetary value corresponding to the agricultural products expected from the flooded land, the surface area of land permanently lost to coastal erosion, the stock of goods lost or damaged, the livestock completely lost, and the work tools lost (**Table 2**).

On agriculture, livestock and fisheries

Rainfall flooding has had a major impact on agriculture. Approximately 35 hectares of crops have been swallowed up by the latest floods in the 08 districts of the three communes of the southwestern coast of Benin. In the livestock/fishing sub-sector, 48 heads of sheep, 63 heads of cattle, 42 heads of goats, 1905 heads of poultry and 1200 fish ponds died by drowning. The damage and losses thus assessed amounted to an average of 61,011,000 CFA francs, broken down into losses (52.94 million) and damage assessed at 8,017,000 CFA francs.

- On trade

All the economic activities located in the flooded area were affected. The rising waters caused material destruction such as means of production (machines), stocks of goods and property. In total, losses of goods estimated at 127,006,000 million CFA francs with losses of 80,014,000 CFA francs and damage estimated at 46,092,000 CFA francs and 6550 working tools were recorded in the eight districts of the three communes visited. In addition to this material damage, there were also losses related to a halt in activity: the rising waters disrupted river navigation and access to agricultural areas. Entrepreneurs, craftsmen, shopkeepers, farmers, etc. are then paralyzed until the receding water level allows access to work areas again. In this context, the inaccessibility of markets for the sale of goods leads to the interruption of income-generating activities, which contributes to a drop in household income and, as a result, to the acceleration of the poverty cycle.

**Table 2.** Financial impacts of coastal risks on housing and socio-economic activities in the communes of Ouidah, Comè and Grand Popo.

Sectoral axes	Damage (millions FCFA)	Losses (millions FCFA)	(millions FCFA)
<b>COMMUNE OF OUIDAH</b>			
<b>Productive sectors</b>	<b>9.68</b>	<b>35.14</b>	<b>44.82</b>
Agriculture, livestock and fisheries	0.77	16.13	16.9
Trade	8.91	19.01	27.92
Industry	0	0	0
<b>Infrastructure Sector</b>	<b>10.05</b>	<b>0.91</b>	<b>10.96</b>
Transportation	3.2	0.29	3.49
Energy	0	0	0
Water and sanitation (including solid waste)	0.65	0.62	1.27
Other infrastructure	6.2	0	6.2
<b>Social sectors</b>	<b>25.87</b>	<b>2.43</b>	<b>28.3</b>
Education	11.38	2.43	13.81
Housing	13.79	0	13.79
Health	0.7	0	0.7
<b>TOTAL (millions FCFA)</b>	<b>45.6</b>	<b>38.48</b>	<b>84.08</b>
<b>COMMUNE OF COME</b>			
<b>Productive sectors</b>	<b>15.48</b>	<b>24.22</b>	<b>39.7</b>
Agriculture, Livestock and Fisheries	1.23	13.8	15.03
Trade	14.25	10.42	24.67
Industry	0	0	0
<b>Infrastructure Sector</b>	<b>24.07</b>	<b>1.46</b>	<b>25.53</b>
Transportation	5.12	0.47	5.59
Energy	0	0	0
Water and sanitation (including solid waste)	1.03	0.99	2.02
Other infrastructure	17.92	0	17.92
<b>Social sectors</b>	<b>42.26</b>	<b>3.88</b>	<b>46.14</b>
Education	18.2	3.88	22.08
Housing	22.06	0	22.06
Health	2	0	2
<b>TOTAL (millions FCFA)</b>	<b>81.81</b>	<b>29.56</b>	<b>111.37</b>

Continued

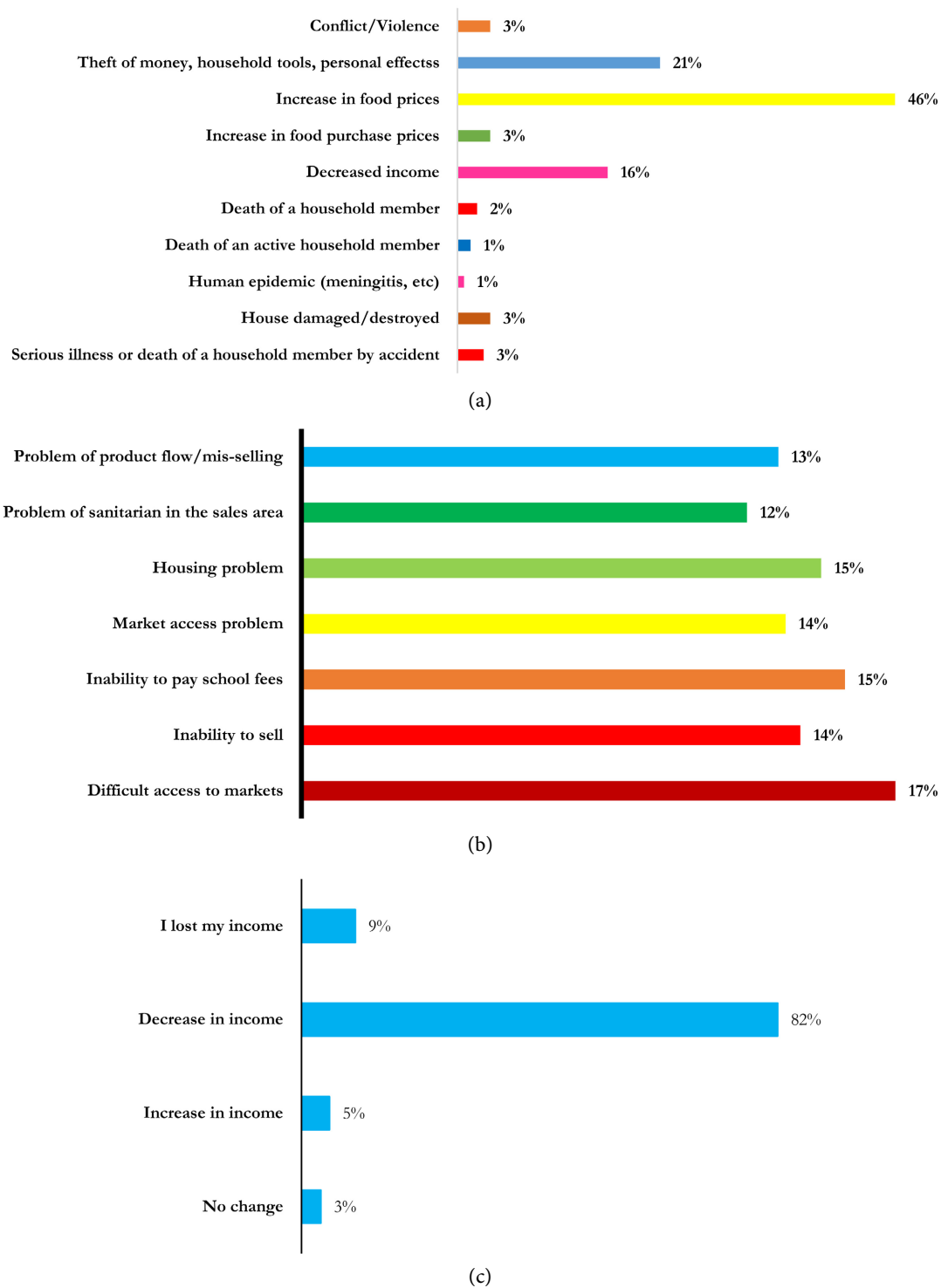
COMMUNE OF GRAND-POPO			
<b>Productive sectors</b>	<b>29.93</b>	<b>73.72</b>	<b>103.65</b>
Agriculture, livestock and fisheries	6.17	23.01	29.18
Trade	23.76	50.71	74.47
Industry	0	0	0
<b>Infrastructure Sector</b>	<b>40.13</b>	<b>2.43</b>	<b>42.56</b>
Transportation	8.54	0.78	9.32
Energy	0	0	0
Water and sanitation (including solid waste)	1.72	1.65	3.37
Other infrastructure	29.87	0	29.87
<b>Social sectors</b>	<b>70.1</b>	<b>6.47</b>	<b>76.57</b>
Education	30.33	6.47	36.8
Housing	36.77	0	36.77
Health	3	0	3
<b>TOTAL (millions FCFA)</b>	<b>140.16</b>	<b>82.62</b>	<b>222.78</b>

- Impacts on food security

In the villages targeted by the survey, the poor are the hardest hit in terms of food security, as the disasters have exacerbated the food insecurity situation of households. They have aggravated the difficulties of households living in poverty and pushed other households that were managing to get by as best they could into precariousness. Indeed, because of the difficulty of accessing the market during floods, women have enormous difficulties in carrying out their income-generating activities (17%), see **Figure 5(a)** and **Figure 5(b)**. The obligation for them to reimburse the credit contracted with microfinance structures or tontines makes this situation even more difficult. Other factors such as: the increase in prices (46%) (linked to the floods), the destruction of food supplies, the loss of tools and personal belongings of households (21%), the drop in income (19%) and the difficulties in preparing food in flooded areas do not make the situation any easier for already poor households (see **Figure 5(a)** and **Figure 5(b)**).

Coastal hazards have significantly reduced people's incomes and livelihoods. These populations face depressed economies with direct impacts on income. **Figure 5(c)** shows the impact of coastal hazards on the incomes of the surveyed populations. Analysis of this figure shows that 82% of households surveyed experienced a drastic decrease in income and 9% reported losing everything due to the forced cessation of activities during periods of flooding and coastal erosion. 5% reported an increase in income due to small-scale transport and service ac-

tivities carried out by these households to cope with the crisis. On the other hand, 3% did not notice any change in their income during the crisis (Figure 5(c)).



**Figure 5.** Socio-economic impacts of coastal hazards and food security. (a) Impact of coastal hazards on social categories (b) Difficulties encountered by women (c) Impact of coastal hazards on household income. Source: Survey results, 2022.

### 4.2.3. Level of Local Knowledge and Control of Coastal Risks

In order to assess the level of understanding of the communities, we have collected from the populations residing in the coastal zone the perception they have of the causes and manifestations of coastal risks

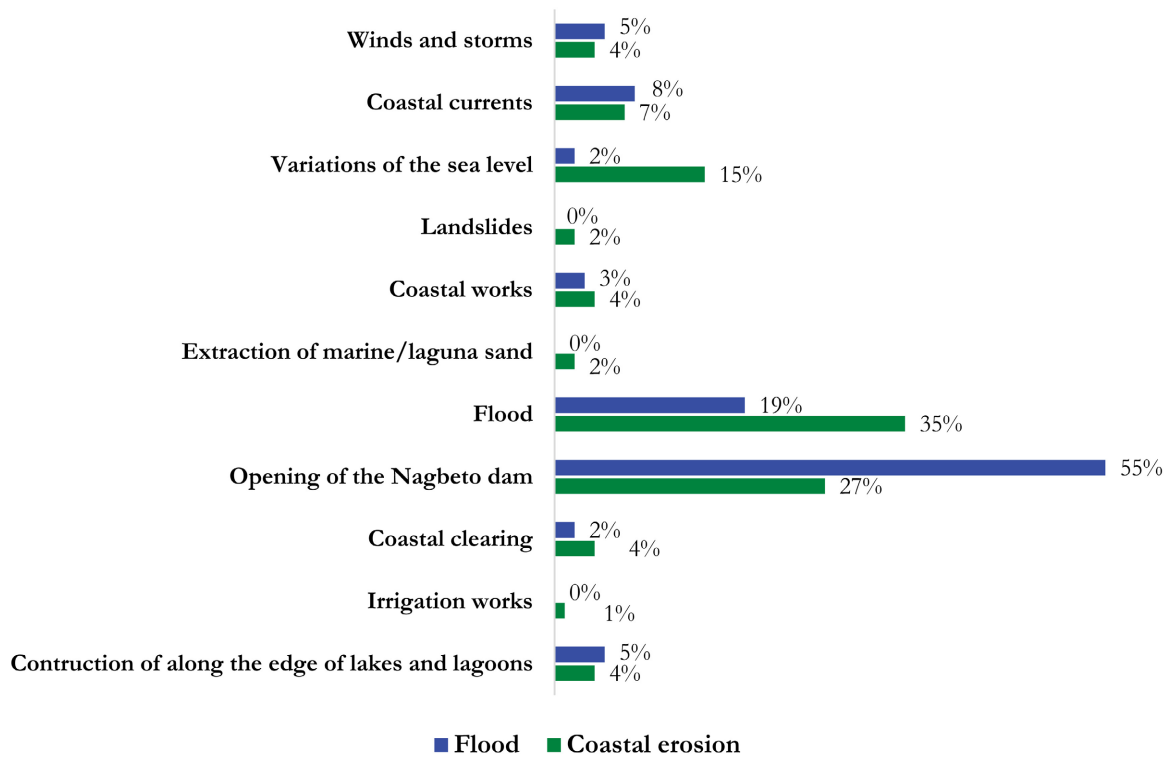
According to **Figure 6(b)**, 73% of the respondents believe that flooding is manifested by the occupation of land by water and 27% believe that it is manifested rather by a loss of land. As for coastal erosion, 56% believe that it manifests itself by a loss of land and 44% by an occupation of land. Four (04) major causes would be at the origin of flooding and coastal erosion. These are: the opening of the Nangbeto Dam, flooding, sea level rise and coastal currents. Other causes were mentioned but with a small proportion (**Figure 6(a)**). Approximately 40% of the respondents said they learned about coastal hazards by direct observation of riverine fluctuations, 16% by rumors, and 12% by a town crier (**Figure 7(a)**). These sources of information take on much more credence when confirmed by rural radio stations and local authorities (**Figure 7(b)**).

Faced with the threats of the almost permanent coastal risks, the riparian populations adopt several palliative techniques. In case of flooding, most of the population migrate to the non-flooded plateaus. On the other hand, in order to continue their daily activities, others prefer to place bags filled with sand and bricks around their houses (**Figure 6(c)**).

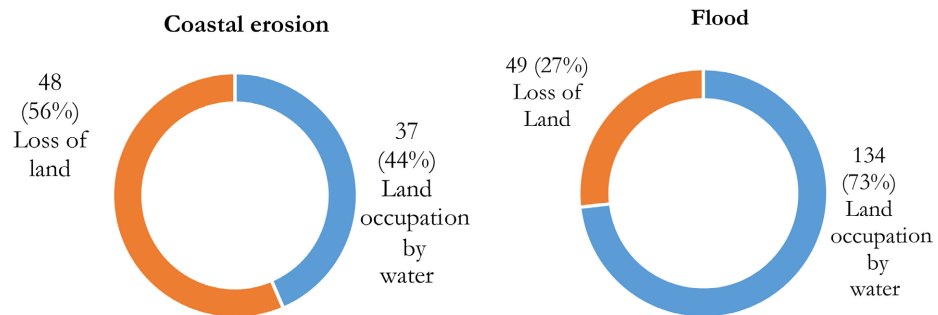
## 5. Discussion

The management of risks and natural disasters remains a challenge in most African countries. This is the case of flooding and coastal erosion that disrupt the coastal zone of Benin. Coastal risks represent permanent threats to the short, medium and long term development of communities. These coastal hazards have become more and more recurrent, causing over the years cumulative effects of suffering and enormous material losses. Coastal erosion and flooding are the main coastal hazards facing West African coasts. Several works and studies have devoted their research to this issue. Since the 1960s, the anthropic pressure on the coastal ecosystems of the Gulf of Benin has only increased. Indeed, the erection of dams on the beds of the Volta (Ghana) and Mono (Togo) rivers, the main providers of sediments, has reduced the sedimentary input on the coasts. According to [20], after the Akossombo dam was put into service in 1964, 60 km from the river mouth, the sediment supply to the coast gradually decreased from 71.106 m<sup>3</sup>/year (in 1964) to 7.106 m<sup>3</sup>/year. This reduction has caused significant erosion which has increased from a rate of 5.5 m/year between 1895 and 2002 [20] to 10 to 12 m/year (currently) at the embouchure and on the east coast of Togo [21]. To mitigate this erosive crisis that has become permanent, coastal defense structures were built in Aného in 1986 (border city with Benin) and then rehabilitated in 2012. Since then, these structures have caused the systematic blocking of sediments towards the Beninese coast and then worsen erosion crisis on the segment of coast located between Hillacondji and Agoué. As an illustration, the erosive episodes recorded over the years show a clear increase with the

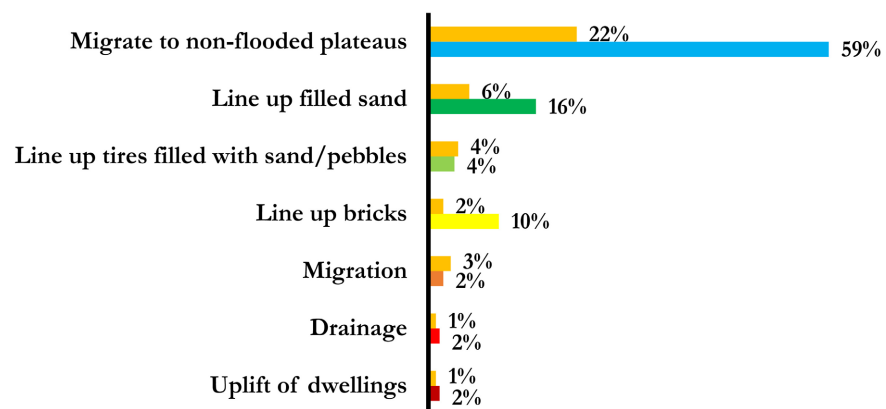




(a)

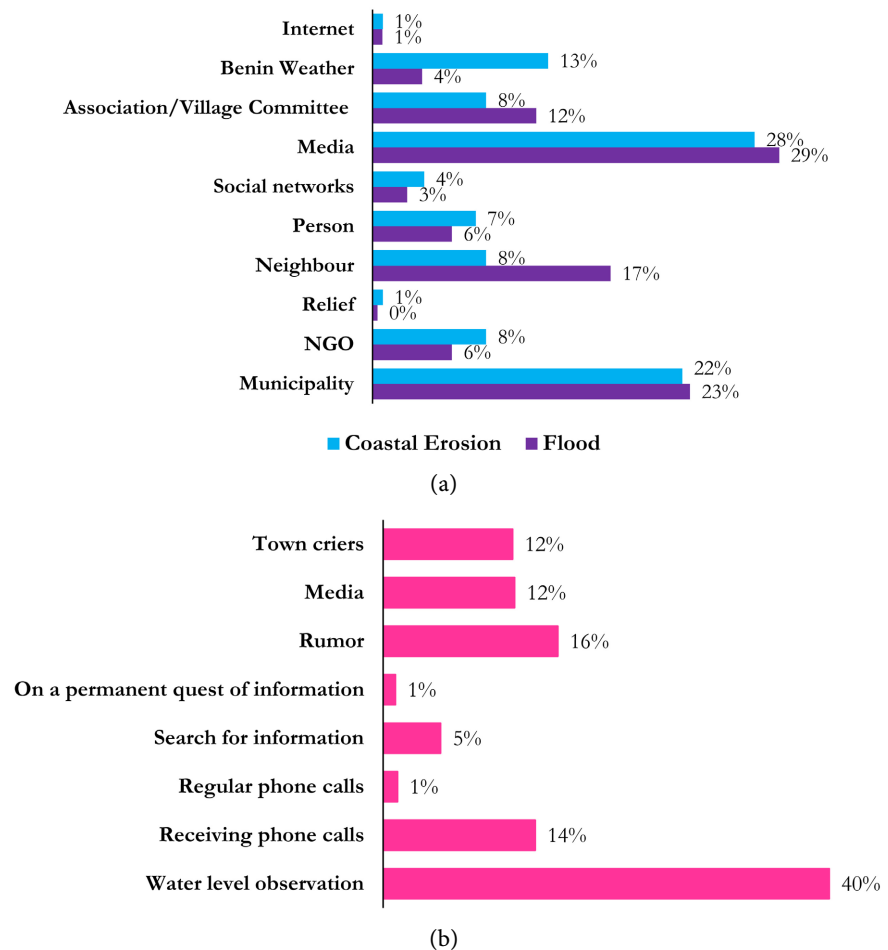


(b)



(c)

**Figure 6.** Local control of coastal risks of the surveyed populations (a) Causes of coastal risks (b) Manifestation in relation to water (c) Practices and techniques for dealing with coastal risks. Source: Survey results, 2022.



**Figure 7.** Sources of information. (a) Causes of coastal hazards according to surveyed populations; (b) Various sources of information. Source: Survey results, 2022.

most exorbitant recession rates. The rate of recession on the segment of coast between Hillacondji and Agoué, previously estimated at 3.25 m/year between 1987 and 2012, has increased to 17 m/year between 2012 and 2018, that is to say an average recession rate equal to 165 m, following the rehabilitation of the groynes of Aného [22]; [23]. In addition, a socio-economic survey on coastal risks in the district of Agoué indicates housing losses equivalent to an amount of 147,262,863f cfa [23]. The study of [24] on the impact of coastal erosion in African coastal cities shows the damage caused by coastal development. To the east of Cotonou on a 6 km stretch of land, about 53 ha of land, 372 dwellings (houses and villas) have been swallowed up by the sea, forcing 1900 people to make a forced move. Apart from its impact on habitat and socio-community infrastructure, coastal erosion has repercussions on human activities. For example, a recent study [25] shows that the resurgence of erosive episodes on the beaches of Thiès (Senegal), which are very attractive and known for their seaside landscapes, has resulted in the destruction of several tourist complexes. In the fishing industry, which provides more than 600,000 direct jobs, coastal erosion and heavy storms lead to the loss of boats and equipment, putting a strain on the daily lives of those involved,

who see their savings dwindle day by day [25]. Floods represent 40% of the 38 natural disasters that occurred in Benin between 1990 and 2018. More frequent in the Niger, Ouémé and Mono basins, these floods caused 99% of the annual loss of assets induced by all natural disasters [26]. If the causes are primarily natural, the extent of the damage observed today is much more attributable to anthropic actions. For example, the extension of human settlements in the flood plains, which were previously colonized only for their agricultural fertility and for flood crops, accentuates the perverse effects of floods on the habitat. This is the case of the city of Jeddah in Saudi Arabia where the uncontrolled urban expansion in the lower reaches of Wadi Assir and Wadi A Asla has aggravated the flooding phenomenon [27]. In recent years, the resurgence of flooding, the traces and after-effects of which are still visible in the communes of Grand Popo, Lokossa, Athiémé and Bopa, testifies to the aggravation of this risk in the lower Mono valley [28].

The massive flooding of the main rivers (Mono and Couffo), the reversal of the direction of the current at the mouth of the river, causing the permanent discharge of sea water, the inadequacy of the existing drainage and sanitation systems as well as the local and national capacity to reduce and manage risks and disasters are all causes that amplify flooding and thus make the populations more vulnerable [29].

Like coastal erosion, flooding affects both people and their environment. In 2010, 55 of Benin's 77 municipalities were affected by flooding. In total, 680,000 people were affected, 46 lives were lost, 55,000 houses were damaged, 455 schools and 92 health centers were partially or completely destroyed, not to mention the impacts on people's health resulting from the destruction of latrines and the slow withdrawal of water. All these losses and damages cost the Beninese economy 127 billion fcfa [29]. In 2019 the flooding, unlike that of 2010, affected only the 21 communes at risk. However, among these communes, 06 namely: Grand Popo, Athiémé, Malanville, Aguégué, Zangnanado and Karimama were severely affected. In terms of agriculture, 4899.1 hectares of crops (all crops combined), as well as several thousand head of animals and fish, were swallowed up by the waters [26] [30]. The cost of losses and damage is estimated at 53,295,000,000 CFA francs [26].

## 6. Conclusions

The southwestern coastal zone of Benin, like the coastal zones of West Africa and the world, is constantly confronted with coastal risks. The communes of Grand Popo, Comè and Ouidah, which were the focus of this study, are exposed to the risks of coastal erosion and flooding, each to varying degrees. Although the origin of most of these risks is linked to extreme weather conditions expressed by exceptional flooding from excess rainfall, the resurgence of these risks is essentially the result of increasingly advanced anthropogenic actions coupled with the absence or poor policy of sustainable disaster management. Of the three communes considered for this assessment, Grand Popo is by far the most vul-

nerable to both coastal erosion and flooding. From the results of socio-economic surveys, the activities most impacted by coastal hazards are firstly trading with 127,006,000 millionxof of loss and damage, followed by agriculture and fishing with 61.11 million xof of loss and damage. Livestock being the least affected activities. Among the losses, the coastal areas also recorded infrastructure losses, the most important of which were losses related to housing (including latrines and wells), schools and to some extent roads.

The populations of the study area have a perfect knowledge of the coastal risks, their impacts and even the conditions and extent of their manifestations. Faced with these coastal risks, they keep a watchful eye by direct observation or by alerting the local authorities. In case of risks, they often prefer to move temporarily to non-flooded plateaus.

### Acknowledgements

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### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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